THE IMPACT OF NATIONAL AIRSPACE SYSTEMS (NAS) MODERNIZATION ON AIRCRAFT EMISSIONS

Operations Research and Analysis (ASD-430)
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Executive Summary

Any change in the National Airspace System (NAS) operational concept or architecture has a potential effect on the global environment. The environmental impacts have significant global implications and are of interest to the International Civil Aviation Organization (ICAO) community. The ICAO Committee on Aviation Environmental Protection (CAEP) is charged with the development of international standards and recommended practices for measuring and controlling aircraft noise and engine emissions. Historically, CAEP activities have been directed toward improving methods for measuring gaseous emissions and considering increases in stringency of the standards. More recently, the CAEP has expanded its consideration to include operational measures that have the potential to reduce aviation emissions, including Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) implementation. The concept that the U.S. community is focusing on for modernization, including CNS/ATM, is Free Flight.

Government and industry agree that a reduction in air traffic control restriction has an enormous potential for time and resource savings. This consensus is well documented in RTCA task force reports and in the National Civil Aviation Review Commission Report. They note that any activity that removes such ATC restrictions represents a move toward Free Flight.

In support of Free Flight, the Federal Aviation Administration (FAA) is investing billions of dollars to provide new/enhanced capabilities through the introduction of CNS/ATM technologies into the NAS. These new capabilities and services are embodied in the government/industry concept of operations. This concept forms the basis for introduction and integration of these technologies in the NAS Architecture, the aviation community's roadmap to modernization. It is expected that with the deployment of these new capabilities, users will get better services, such as more wind-optimized cruise trajectories and altitudes and more efficient surface traffic operations.

This report provides further evidence to support the pursuit of Free Flight initiatives by extending the analysis to include associated environmental benefits. In essence, if Free Flight results in lower fuel burn by users, a corollary benefit is less pollution—a clear environmental benefit that is often overlooked.

In particular, the study evaluated the fuel and emission benefits of Free Flight by aircraft type and phase of flight. Calculations for aircraft emissions were made for pollutants directly produced within the engine combuster and emitted at a rate depending on the temperature and thrust of the engine—in this instance, specifically for nitrogen oxides (NOx), hydrocarbons (HC) and carbon monoxide (CO). These calculations used emission indices in terms of unit of pollutant per 1,000 units of fuel burned for each phase of flight. The emissions for other gases such as carbon dioxide and sulfur dioxide were not included as part of this study.

Two scenarios were developed for use throughout the study, a baseline scenario representing the future airspace system without modernization and an enhanced scenario representing key technologies and operational capabilities that are planned for introduction into the NAS. Comparison of these two scenarios indicates that the CNS/ATM enhancements to the NAS have a

potential annual fuel savings of over 10 billion pounds in the year 2015, which represents a savings of 6% over what would have been expended without NAS modernization. The phase of flight above 3,000 feet, which offers capability for more fuel efficient flight operations, accounts for 94% of the savings, with remaining savings occurring on the surface and below 3,000 ft. This combined fuel savings translates to an annual reduction in emissions of over 209 million pounds of NOx, 211 million pounds of CO, and 59 million pounds of HC, representing savings of over 9%, 12%, and 18%, respectively.

Findings from this study were reported at the International Civil Aviation Organization (ICAO) Worldwide CNS/ATM Systems Implementation Conference in May 1998 and are highlighted below.

Annual Savings in Millions of Pounds

Phase of Flight	Fuel	NOx	CO	HC
Above 3,000	9,683	204.3	197.1	56.7
Below 3,000	219	4.0	1.1	0.1
Surface	358	1.2	13.2	3.1
Total	10,259	209.5	211.4	59.9
% Savings	6.1%	9.9%	12.7%	18.0%

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INTRODUCTION

1.1 Organization

This report compiles the sources, tools, methodologies, and results of the impact study and is organized as follows. Section 1 provides a discussion of Free Flight, the Air Traffic Services Concept of Operations, and the National Airspace System (NAS) Architecture, all of which formed the technological base for the study. The scope of the study is also found in this section. Section 2 contains the broad assumptions applied to the analysis.

Section 3 introduces the modeling scenarios and discusses their development. Data preparation necessary to begin the analysis is presented in Section 4. The analysis of the baseline and enhanced scenarios is contained in Section 5 and is organized under four major headings: Airborne, Surface, Oceanic, and Emissions. Section 6 summarizes the results of the analysis and includes a discussion on extending the results to annual savings and converting the fuel savings to dollars. Section 7 covers the study's conclusions. The appendices provide additional detail used in the analysis, a description of the tools and models, and a list of the study's participants.

1.2 Background

The NAS Architecture is the U.S. aviation community's roadmap for modernization. It provides a high-level description of NAS capabilities and services, the functions to be performed, their dependencies and interactions, and the flow of information among the functions. It also describes the schedule and costs necessary to implement the capabilities and services defined in the Air Traffic Services Concept of Operations.

Any change in concept or architecture has a potential effect on the global environment. The environmental benefits to be gained from a more efficient airspace system have significant global implications and are of interest to the International Civil Aviation Organization (ICAO) community. The ICAO Committee on Aviation Environmental Protection (CAEP) is charged with the development of international standards and recommended practices for measuring and controlling aircraft noise and engine emissions. Historically, CAEP activities have been directed toward improving methods for measuring gaseous emissions and considering increases in stringency of the standards. More recently, the CAEP has expanded its consideration to include operational measures that have the potential to reduce aviation emissions, including Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) implementation. The concept that the U.S. community is focusing on for modernization, including CNS/ATM, is Free Flight.

"Free Flight is defined as the safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real-time. Air traffic restrictions are imposed only to ensure separation, to preclude exceeding airport capability, to prevent unauthorized flights through special use airspace, and to ensure safety of flight. Restrictions are limited in extent and duration to correct the identified problem. Any activity that removes restrictions represents a move towards Free Flight."

On October 31, 1995, RTCA Task Force 3 on Free Flight Implementation published a final report that defined the Free Flight operational concept, evaluated the Free Flight Architecture and technology needs, and identified an incremental transition to Free Flight. Task Force 3 expanded on the definition of Free Flight to include: "... user is granted both maximum flexibility and guaranteed safe separation. The goal is not only to 'optimize' the system but also to open the system for each user to 'self-optimize'." Self-optimization is the key to understanding the extent of Free Flight's reach, as well as Free Flight challenges.

"Free Flight is not limited to airspace--its spatial constraints are gate to gate, but Free Flight reaches into a flight's prehistory by providing increased flexibility in flight planning. In the broadest sense, Free Flight is the unrestricted opportunity for all to use the limited airspace in a manner that is efficient, effective, and equitable."[1]

Free Flight's influence on NAS modernization promotes the easing of ATC restrictions. As a result, there is a general consensus between government and industry that this easing of ATC restrictions has an enormous potential for time and resource savings for future flights. This consensus is well documented in RTCA task force reports and in the National Civil Aviation Review Commission Report. In response, the FAA is developing a concept for investing in planning and new technologies for CNS/ATM in the NAS.

In September 1997, FAA Air Traffic Services (ATS) published *A Concept of Operations for the National Airspace System in 2005* reflecting the joint efforts of the FAA and Industry, through RTCA, to implement Free Flight. That document describes the evolutionary changes needed to meet the user needs for greater flexibility in planning and conducting flight operations. Specifically, the air traffic system will evolve in the areas of airspace and procedures, roles and responsibilities, equipment, and automation. Once fully implemented the Concept of Operations will provide the following:

- Prior to flight, *sharing of real-time information* between the users and the service provider that ensures greater system flexibility—including departure time and traffic load

[1] Free Flight Action Plan Update, April 2, 1998, pp. 2-3

prediction and flight plans that optimize around weather, outages and traffic density constraints.

- Prior to taxiing, surface automation that facilitates the *coordination of all surface activities*, including runway and taxiway assignments based on projected runway loading and surface congestion (user preference and environmental considerations such as noise abatement will be considered).

- Arrival runway and taxiway assignments based on gate assignment and surface congestion, providing the *most efficient arrival and taxi execution.*

- Departure assignments made when the flight profile is filed, and updated accordingly until the time of pushback providing the best sequence to departure threshold, *maximizing runway throughput and minimizing queue delay*.

- During departure and arrival operations, decision support systems that *assist the service provider in providing runway assignments and in merging and sequencing traffic,* based on accurate traffic projections and user preferences.

- During en route/cruise operations, improved decision support tools for conflict detection, resolution, and flow management that allow *increased accommodation of user-preferred trajectories, schedules, and flight sequences.*

- For oceanic flights, global satellite navigation and a communication system using satellite-based communications and electronic message routing—enabling the oceanic system to be more interactive and dynamic and supporting cooperative activities among flight crews, Airline Operations Centers (AOCs), and service providers. This will result in *reduced separation between aircraft, and more flexible and preferred routes.*

These new capabilities and services are embodied in the government/industry concept of operations, which forms the basis for the introduction and integration of these technologies in the NAS Architecture.

This report describes the collaborative effort involving industry and government in supporting a study of these CNS/ATM enhancements and their benefits to users and the environment. Included are the analysis and findings of the study, along with participants from the FAA, National Aeronautics and Space Administration (NASA), Air Transportation Association (ATA), and three airlines. (For a list of study team participants and advisors, see Appendix A.) The study also contributes to the ICAO CAEP activities, Free Flight and validation of concept of operations and provides supporting information to issues that were discussed at the Worldwide Environmental Conference held in Kyoto, Japan in December 1997.

Findings from this study were presented at the ICAO Worldwide CNS/ATM Systems Implementation Conference in May 1998 and are expected to continue to receive environmental interest in the future.

1.3 Objective

The objective of the study was to examine benefits of the planned CNS/ATM enhancements in accordance with the Concept of Operations and the NAS Architecture V3.0 Draft, dated December 1997, to support Free Flight and NAS Modernization.

In particular, the study evaluated the fuel and emission benefits of the planned CNS/ATM enhancements by aircraft type and phase of flight, i.e., taxi-out, climb, cruise, approach, and taxi-in. Calculations for aircraft emissions were made for nitrogen oxides (NOx), hydrocarbons (HC), and carbon monoxide (CO). These were chosen because they were the principal emissions included in previous studies of this nature. Other pollutants, such as carbon dioxide and sulfur dioxide, are also emitted but were not included as part of this study.

1.4 Scope

This analysis covers the planned CNS/ATM concepts and technologies that are outlined in the NAS Architecture V3.0 Draft for the U.S. controlled oceanic airspace, en route and terminal airspace, and airport surface operations. The time frame for the study is from 1996 to 2015.

Section

2

ASSUMPTIONS

The study began with the development of key assumptions regarding baseline and future operations.

- Fuel and emission calculations cover only Instrument Flight Rule (IFR) flight plan traffic.
- The airspace structure and procedures will be modified in the future years of the study to incorporate CNS/ATM enhancements. These enhancements are described in paragraph 3.3.
- Systems will be deployed and users will equip according to the schedules in the NAS Architecture V3.0 Draft. These systems will reach full capability as planned currently.
- All airport improvements that are planned currently and any near-term procedural improvements were used in both scenarios.
- The 1996 Terminal Area Forecast (TAF) was used to forecast future traffic.
- A fleet mix forecast, derived from ICAO, NASA, and FAA Office of Aviation Policy and Plans (APO) forecasts, was used as the current and future domestic fleet mix.

More detailed assumptions, applicable to specific analysis areas, were developed during the analytical process. For the report, they are listed in the section to which they apply and also in Appendix B.

Section

3

MODELING SCENARIOS

3.1 Baseline and Enhanced Scenarios

Once the assumptions were agreed upon, an analytical framework was used to create two scenarios that reflect the current operations (baseline scenario) and the future concept of operations (enhanced scenario) in the NAS.

Using 1996 as the base year, the baseline scenario was developed to represent today's NAS operational procedures, enhanced only for committed and projected near-term Airport Improvement Plan (AIP) and procedural improvements. Flight data was collected for aircraft operating in the existing air traffic control (ATC) system of route structures and sector configuration. November 12, 1996, was selected to be a representative day for the baseline scenario, from which all future measurement points were derived.

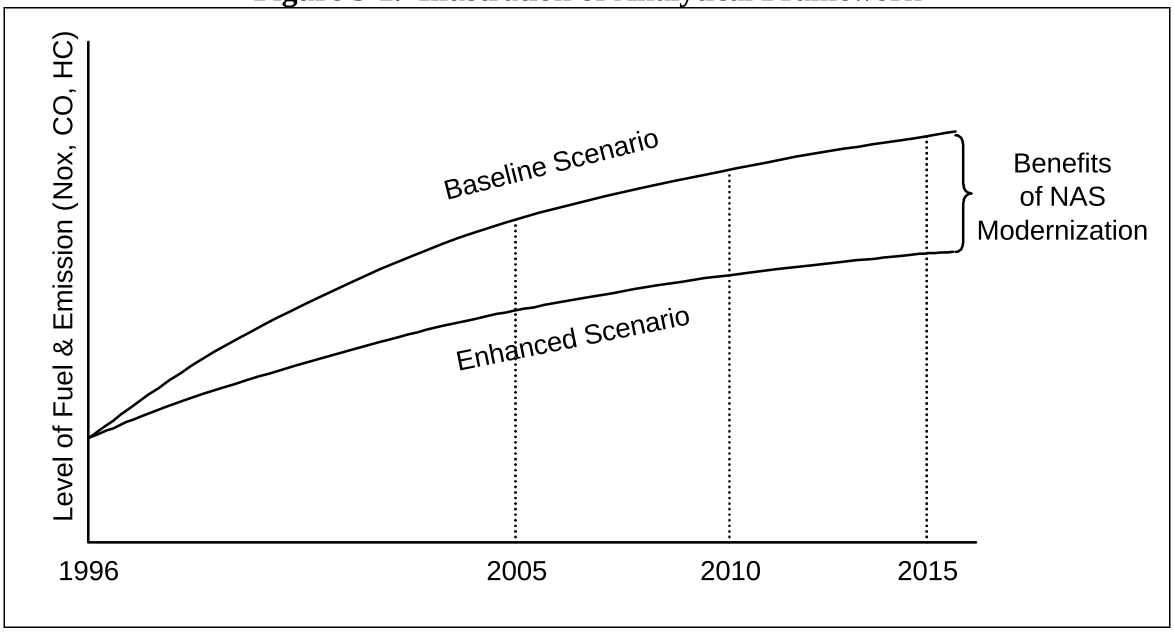
From this base year, the baseline scenario was estimated for three future time intervals of 2005, 2010, and 2015 by applying forecast traffic growth and fleet mix changes. Flights for future years were constructed by increasing the number of flights commensurate with the traffic growth forecasts. The types of aircraft in future inventories were adjusted based on fleet mix forecasts. This set of flights was "flown" in the baseline scenario to estimate fuel consumption and corresponding emissions for 1996, 2005, 2010, and 2015 in an ATC system with only planned AIP and procedural improvements.

The enhanced scenario was derived from the baseline scenario by phasing in key technologies and capabilities to the NAS as outlined in the NAS Architecture V3.0 Draft. These capabilities will provide new services to users, such as direct routes, optimal climb and descent, and expedited taxi clearances. The enhanced scenario reflects capabilities at each of the time intervals noted above.

The flight plans developed for the baseline scenario were used to create wind-optimized flight trajectories for the enhanced scenario. These wind-optimized trajectories were then "flown" in a modernized ATC system with planned AIP and procedural improvements *and* CNS/ATM enhancements to estimate fuel consumption and corresponding emissions in an ATC system reflecting the ATS Services Concept of Operations.

Simulated fuel/emission estimates of users operating in the future NAS with no modernization, (baseline scenario) versus what could be achieved in a NAS with the planned CNS/ATM capabilities and optimal routings, (enhanced scenario) were compared at each of the three time intervals. Comparison of these scenarios, with and without modernization, thus yields incremental estimates of the fuel savings and emissions' reductions for the years 2005, 2010, and 2015. An illustration of the analytical framework, based on the phased-in implementation of new operational capabilities, is shown in Figure 3-1. Further description of the scenario development follows.

Figure 3-1. Illustration of Analytical Framework



3.2 Development Steps Common to Both Scenarios

The following paragraphs discuss how the baseline set of flights was determined, how traffic growth was incorporated, how the planned physical airport improvements and procedural improvements will impact airport capacity, and how the adjustments were made to the fleet mix. These activities are common to both scenarios.

3.2.1 Enhanced Traffic Management System

The Enhanced Traffic Management System (ETMS) was used to develop the study's baseline set of flights, and the ETMS Flight Plan messages were used to construct each aircraft's flight plan database (see Appendix C for additional information on ETMS). ETMS data is derived from several primary sources. The two relevant sources for this study were the Official Airline Guide (OAG) and the NAS computers at the 20 Air Route Traffic Control Centers (ARTCCs). The OAG provided ETMS with the planned schedules of all flights arriving in and/or departing from the U.S. or Canada. The NAS computers provided the filed flight plans and the current state of all Instrument Flight Rules (IFR) air traffic in the CONUS.

3.2.2 Future Demand Generator Tool

The Future Demand Generator (FDG) Tool of the NAS Performance Analysis Capability (NASPAC) Simulation Modeling System (SMS) was used to project traffic growth to 2005, 2010, and 2015. The sources for projected traffic operations were the FAA, APO, which publishes the TAF from present to 2010, and ICAO. The ICAO's world projection was used to complement the FAA/APO projection for the CONUS and forecast oceanic traffic growth. (Additional information on the FDG is found in Appendix C.)

An algorithm was applied to increase the traffic found in the present schedule for each of the 80 airports modeled in NASPAC by applying annual growth factors recorded in the 1996 TAF. The current FDG contains 300 airports that serve air carrier operations predominately and 404 general aviation airports from which growth is adjusted. Traffic growth was projected for both air carrier and general aviation traffic.

3.2.3 Airport Improvement Plan (AIP) and Procedural Improvements

Planned physical airport and ATC procedural improvements that were modeled in both scenarios are discussed in the next two sub-sections. (Additional detail is found in Appendix D.)

3.2.3.1 AIP Physical Airport Improvements

Physical changes to an airport can have a substantial impact on airport capacity. The effect can range from opening a new airport to adding new taxiways that streamline air traffic operations. Runways can be extended to air-carrier length, allowing the airport to accommodate larger aircraft. Airport capacity can be increased by adding to the number of gates or adding room for aircraft to maneuver in the ramp area. However, the change that generally has the greatest impact on capacity is adding a new runway.

Arrival capacity generally is more restrictive than departure capacity. Therefore, the increase in maximum arrival capacity is cited as a measure of the capacity increase. (See Appendix D for a discussion of the physical airport improvements that are expected to increase airport capacity during the 1996-2015 time frame.)

Key input for both scenarios due to physical airport improvements was based on the 1997 Airport Capacity Enhancement Plan and input from the Office of Airport Planning and Programming (APP). The information used as part of the study is as follows:

- Maximum hourly arrival capacity will increase at 16 of the 80 modeled airports during the 1996 to 2005 time frame.

- Maximum hourly arrival capacity will increase at 7 additional airports by 2010.

3.2.3.2 ATC Procedural Improvements

Airport capacity can be impacted significantly by changes in ATC procedures. New procedures can increase the use of existing runways, or they can work in concert with new runways and with CNS/ATM improvements. The following procedural improvements are reflected in the increased airport capacities for both scenarios.

- Converging IFR approaches will be added to independent IFR parallel approaches. This procedure will increase airport capacity greatly at airports with the appropriate configurations, such as Chicago O'Hare (ORD) and Washington Dulles (IAD).

- Independent converging IFR approaches can be flown to converging runways with sufficient separation between runway thresholds, or to airports without sufficient separation, but at higher approach minimums. This procedure substantially increases IFR capacity at airports without parallel runways.

- Dependent Converging Instrument Approaches (DCIA) allows controllers to direct two dependent streams of arriving aircraft to converging and even intersecting runways. Consecutive arrivals in each stream are staggered to separate the aircraft. A modification to the ARTS, called the Converging Runway Display Aid (CRDA), enables controllers to maintain the correct separations.

- In some cases, the addition of a navigation aid (NAVAID) can increase airport capacity by allowing a new procedure such as dependent (staggered) parallel approaches. For example, at Portland (PDX), a recently added Instrument Landing System (ILS) allows controllers to use these approaches.

(Appendix D provides an overview of the procedural improvements predicted for airports modeled in detail in NASPAC for the 1996 - 2010 time period.) Beyond the 2010 time frame, there are no known, new procedures that could be included in this analysis; therefore, all improvements implemented by 2010 are considered to be in effect at 2015.

Table 3-1 summarizes the projected increase in the maximum hourly arrival capacities due to both the airport (physical) and procedural improvements for the 1996-2010 time frame.

Table 3-1. Summary of Airport and Procedural Improvements for 1996-2010

Improvement	Number of Affected Airports	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity	
		(Percent)	Add'l Hourly Ops
Physical Improvements: 1996-2005 (excluding close parallels and runways designed for use with Precision Runway Monitor	12	53%	22

Improvement	Number of Affected Airports	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity (Percent)	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity Add'l Hourly Ops
(PRM)			
Physical Improvements: 2006-2010 (excluding close parallel at Los Angeles International Airport (LAX))	6	40%	16
Procedural Improvements: 1996-2010	8	41%	17

3.2.4 Fleet Mix

The fleet mix used for this study was developed using data from NASA/LMI, ATA, ICAO, and APO. The current fleet mix was compiled using data from NASA/LMI's Aviation System Analysis Capability (ASAC) database and ATA input. Since the ASAC database has information on passenger aircraft only, this data was augmented with information from ATA to account for cargo aircraft. Using both of these sources, the baseline fleet for 1995 was obtained and then extrapolated to 1996, 2005, 2010, and 2015. The future fleet mix does not assume incorporation of advanced engine technologies resulting from ongoing research activities. Additional information on fleet mix calculations is shown on Appendix E.

ICAO forecasts the world fleet out to 2015 separating aircraft by class (number of seats). Using ICAO's forecast for each class, and the U.S. fleet for 1995 developed above, the U.S. forecast for each class was extrapolated from the world forecast based on the assumption the proportion of U.S. aircraft in the world fleet would remain constant.

The U.S. forecast for each class was then used as a basis for estimating the future inventory for each type of aircraft by assuming that the percentage of each aircraft type in each class of aircraft will remain the same in the future.

The resulting U.S. forecast was then validated and updated using APO's forecast for Stage 2/3 aircraft. The term Stage 2/3 aircraft refers to aircraft that meet Stage 2/3 noise levels as prescribed in Title 14 of the Code of Federal Regulations (14 CFR), part 36. Stage 2 aircraft are being removed from the fleet inventory under section 91.853 of 14 CFR, part 91. Adjustments to the future aircraft inventory were made to account for the phasing out of these aircraft. Aircraft that currently are out of production (such as the 727 and 737-100/200) were reduced in the future fleet, and other aircraft in the same class were increased to compensate. 1996 fleet totals were obtained by interpolating between the 1995 total and 2005 total assuming a constant increasing or decreasing rate between those years. The resulting U.S. forecast is shown in Figure 3-2.

Figure 3-2. U.S. Fleet Forecast

Class	Type	1996	2005	2010	2015
20-40	DHC6	64	108	131	155
	DHC8	144	244	296	349
	D328	37	63	76	90
	Embr120	237	402	488	576
	J31	87	148	180	212
	J32	83	141	171	202
	J41	39	66	80	95
>40 seats	ATP	12	36	48	61
	ATR-42	100	299	400	506
	ATR-72	51	153	204	258
	CV-580	18	54	72	91
	CRJ	36	108	144	182
	DHC7	29	87	116	147
	F27	14	42	56	71
Total (Class 1)		951	1950	2462	2994
	BAE146	41	47	52	57
	A320	109	187	267	306
	DC8	102	119	131	143
	DC9	454	408	328	328
	707/720	2	2	3	3
	727/100-200	680	147	0	0
	737-100	11	0	0	0
	737-200	312	90	5	0
	737-300	482	561	618	673
	737-400	94	123	135	147
	MD-81/82/83/87/88	615	775	915	1010
	MD-90	11	13	14	16
	F-100	130	151	166	181
	F-28	70	81	90	97
Total Class 2 (81-150 Seats)		3273	3163	3324	3618
	757	660	1803	2294	2592
	A310	41	79	99	115
Total Class 3 (151-210 Seats)		701	1882	2393	2707
	L1011	101	49	53	53
	DC10	176	205	175	175
	747-SP	4	0	0	0
	767	224	483	611	854
	777	12	159	218	251
	A300	73	225	298	431
Total Class 4 (211-300 Seats)		591	1121	1355	1764
	MD11	55	70	93	117
	747-100	59	50	50	50
	747-200	62	60	53	52
	747-400	47	91	126	161
Total Class 5 (301-400 Seats)		223	271	322	380
	XX (future design)	0	39	80	133
Total Class 6 (401-500 Seats)		0	39	80	133
	747-SR	0	19	92	144
Total Class 7 (501-600 Seats)		0	19	92	144
TOTAL (Class 2-7)		**4787**	**6494**	**7566**	**8745**

The preceding paragraphs have described the steps taken and resources used that were common to the development of both scenarios. The remainder of Section 3 is devoted to enhanced-scenario development.

3.3 Development of the CNS/ATM Enhanced Scenario

The enhanced scenario was developed from the baseline by adding planned CNS/ATM enhancements to the NAS as outlined in the NAS Architecture and summarized in Figure 3-3. The combination of key technologies provides users with improved capabilities eventually leading to implementation of the ATS Concept of Operations and Free Flight. This study made no attempt to assess the relative contribution of each technology, but concentrated on what the capabilities would bring to users. The principal capabilities assessed during this study were extracted from the ATS Concept of Operations, which when fully implemented will provide a more efficient airspace system through increased information sharing, automated decision support tools, and relaxation of air traffic control restrictions.

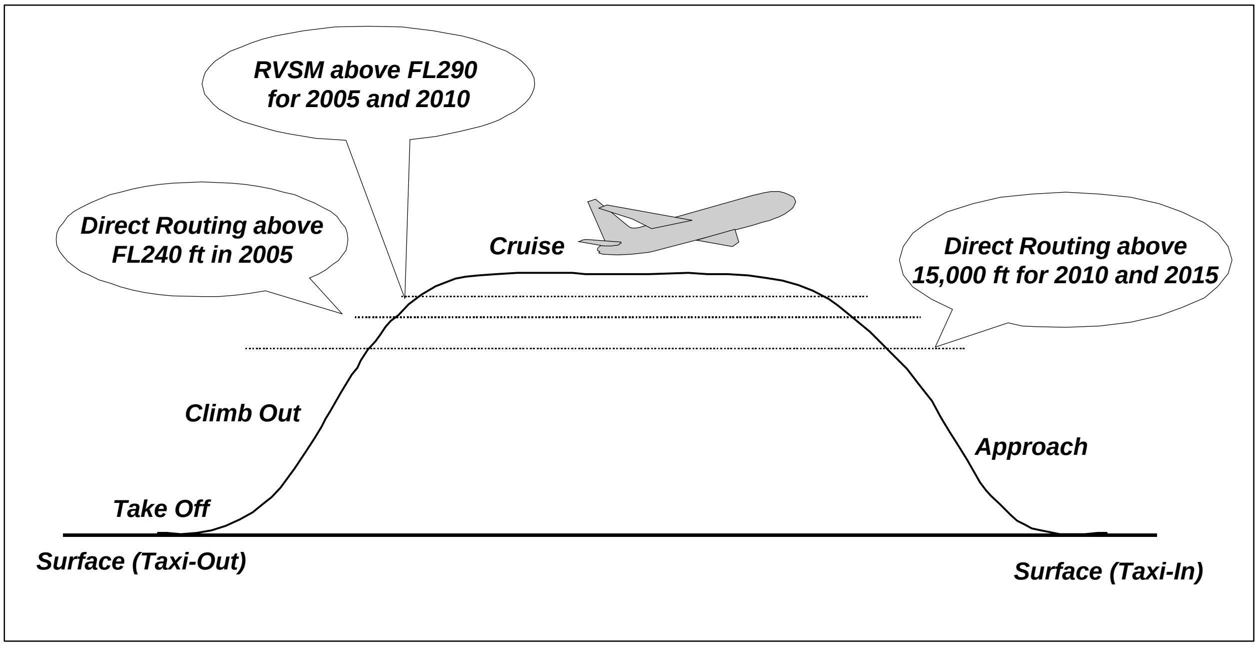
Figure 3-3. Overview of CNS/ATM Enhancements

Year	Key Technologies	New Capabilities
2005	• Controller-Pilot Data Link Communication • Automatic Dependent Surveillance – Broadcast (ADS-B) (Air to Air) • Passive Final Approach Spacing Tool • Traffic Management Advisor, Single Center • Initial Conflict Probe • Integrated Terminal Weather System • Surface Movement Advisor	• Reduced Vertical Separation (RVSM) above FL290 • Optimal climb • Wind-optimized Direct Routes above FL240 • Improved arrival/departure procedures • Expedited taxi clearance • 50/50 Oceanic Separation
2010	• Limited Digital Air/Ground Comm. • GPS Wide Area/Local Area Augmentation • Active Final Approach Spacing Tool w/Wake Vortex • Terminal Automation Enhancements • ADS-B ground stations • Surface Management System	• RVSM above FL290 • Optimal climb and descent • Wind-optimized Direct Routes above 15,000 feet • Improved arrival/departure procedures • Enhanced surface management • 30/30 Oceanic Separation
2015	• Digital Air/Ground communications • Full Conflict Probe • New Traffic Management Decision Support System	• Cruise climb/descent • Wind-optimized Direct Routes above 15,000 feet • Acceptance rates for instrument conditions equal to visual conditions • Enhanced surface management • 30/30 Oceanic Separation

3.3.1 CNS/ATM Enhanced Scenario - En Route Capabilities

For the en route environment, improved capabilities are most evident in reduction in separation, more efficient climb and descent, and wind-optimized direct routing. By 2005, improved aircraft position accuracy and communication will lead to optimal climb procedures, wind-optimized flight trajectories above FL240, and a reduction in vertical separation above FL290. By 2010, further enhancements are expected to provide for optimal climb and descent, and allow wind-optimized trajectories as low as 15,000 feet. By 2015, vertical separation standards will no longer apply and aircraft will be allowed to select their optimal cruise climb and descent and fly wind-optimized trajectories above 15,000 feet. The evolution of the en route capabilities is shown in Figure 3-4.

Figure 3-4. Evolution of En Route Capabilities



The capabilities described above were incorporated into the study by using simulation and analysis tools to modify flight trajectories accordingly at each point in the future, and by calculating the resulting flight times and fuel consumption by phase of flight.

3.3.2 CNS/ATM Enhanced Scenario - Terminal Area Capabilities

Improvements in arrival and departure procedures in terminal airspace are expected to improve airport capacities, eventually leading to acceptance rates for instrument conditions equal to that which is obtained under visual conditions. Enhanced surface management is expected to reduce taxi delay.

CNS/ATM terminal area improvements were modeled in the enhanced scenario. (See Appendix D, Section II for a detailed summary of each system.) Improvements were modeled by adjusting airport arrival and departure capacities, and taxi times based on performance metrics, investment analyses, and cost-benefit studies.

Table 3-2 lists the estimated increase in maximum IFR arrival capacity expected from the CNS/ATM improvements. The Integrated Terminal Weather System (ITWS), Weather Systems Processor (WSP), and Center-TRACON Automation System (CTAS), although applicable at several airports, provide a lesser increase in capacity than other CNS/ATM improvements. The Precision Runway Monitor (PRM), Automatic Dependent Surveillance-Broadcast/Cockpit Display of Traffic Information (ADS-B/CDTI) parallel approaches, and Wide Area Augmentation System (WAAS)/Local Area Augmentation System (LAAS) parallel approaches provide the greatest increase in arrival capacity. Each allows an airport to operate another independent stream of IFR arrivals. In addition, ADS-B/CDTI may increase airport throughput by increasing the amount of time aircraft can fly in visual meteorological conditions (VMC) by up to 13%.

Table 3-2. CNS/ATM Enhanced Scenario Improvements

CNS/ATM Improvements	No. of Affected Airports	Average Estimated Increase in Maximum Hourly IFR Arrival Capacity	
		Percent	**Add'l Ops**
WAAS or LAAS Parallel Approaches	5	52%	15
PRM	5	30%	16
ADS-B/CDTI Parallel Approaches	5	33%	19
ITWS	45	8%	5
CTAS	41	4%	3
WSP	1	7%	5

Section

4

DATA PREPARATION

This section describes the data preparation required to build the baseline and enhanced scenarios. A detailed discussion of data preparation is located in Appendix F.

As the data preparation process began, the following assumptions were applied to the scenarios:

- The baseline scenario assumes growth in traffic, changes in fleet mix, and continuous support of airport and procedural improvements.

- The enhanced CNS/ATM scenario includes the same assumptions used for the baseline scenario and the addition of new technologies and capabilities.

Data preparation for the scenarios began with the determination of a base day (see Paragraph 3.1). Once this was completed, the data preparation activities moved to incorporating the forecasted traffic growth, assigning aircraft types, assigning tracks, and developing flight profiles.

4.1 Traffic Growth

Traffic growth refers to projecting the base day aircraft operations to the out years (2005, 2010, and 2015), while accounting for projected demand, fleet modernization, and the acquisition of new aircraft.

To build an extension to the base day, two sets of flight data were generated for each of the future years (2005, 2010, and 2015). The first set consisted of flight data for all scheduled commercial and air taxi/commuter flights. The second set consisted of all general aviation and military flights.

The initial base year was constructed from the scheduled commercial and air taxi/commuter flights in the OAG for November 12, 1996. The origin airport, destination airport, scheduled times, flight identifier, and aircraft type were obtained for each scheduled flight in the NAS.

Along with the scheduled flights, the general aviation and military flights were obtained from the November 12, 1996, ETMS data. Flights were identified as general aviation or military based upon their flight identifiers. A set of flight data was obtained for these flights consisting of the origin airports, destination airports, actual times of flight, and aircraft type.

The scheduled flights and the general aviation and military flights combined to capture a majority of the activities in the NAS. The next step was to increase the traffic to reflect the projected demand as annotated in the TAF.

The above data sets were input into the FDG (see Paragraph 3.2.2) to increase the traffic demand to the levels expected for 2005, 2010, and 2015. The FDG provided the future flights. Once the new flights were obtained for each scenario, the aircraft types were modified in each year to account for fleet modernization and acquisition of new aircraft (see Paragraph 4.2). Trajectories were then assigned to each flight (see Paragraph 4.4 and 4.5), first in the baseline scenario and subsequently in the enhanced scenario. The enhanced scenario was optimized for the future Concept of operations.

4.2 Assignment of Aircraft Types

After the new flight was determined, an aircraft type was assigned to the flight. A database of fleet mix for the specific future year was used. For each future year, the fleet mix, consisting of the number of each aircraft type (e.g., B737) projected to be in service for the respective year (see Figure 3-2), was obtained. The following assumptions were made:

- New aircraft were added to the list by assuming that they would fly the same distribution of stage lengths as an aircraft in the same category.

- New aircraft would fly the same number of legs per aircraft per day as similar aircraft.

Each new flight generated by the FDG (see FDG in Paragraph 3.2.2) was assigned an aircraft type based on the aircraft equipment of jet or turboprop and its stage length. (See Appendix F for the methodology used in this activity.)

4.3 Assignment of Tracks

Once the flight origin and destination were identified and the aircraft type was assigned to the flight, a track was assigned. A track consists of a series of points between the flight's origin and its destination. The assignment of a track to a flight is explained in the following steps.

- A set of all filed tracks between city pairs (origin and destination) is built from the ETMS data set.

- A track is selected randomly from the set of filed tracks, based on its origin and destination.

For example, using the ETMS data set, a query is built to extract all flights flying between ORD and Los Angeles International Airport (LAX). The next step is to filter the reduced data set only for flights with a specific aircraft type (e.g., B737). From this data set, randomly select a track and assign it to the new flight.

Once the track has been assigned, the next step is to complete the flight trajectory by assigning altitude and speed.

4.4 Assignment of Trajectories - Baseline Scenario

A flight trajectory is made up of three segments: climb, cruise, and descent. In the baseline scenario, speed and altitude trajectories were assigned to each flight as a function of the track, aircraft type, desired cruise altitude, and airspeed en route. For each aircraft type,

- The climb and descent trajectory indicated the sequence of altitudes and airspeeds, and

- The cruise trajectory indicated the flight moving along a route at the specified airspeed and altitude.

For the general aviation, or unscheduled aircraft, trajectories were assigned based on their actual observed trajectories reported in the ETMS. The trajectories of new General Aviation (GA)/military flights, added by the FDG, were obtained by copying the trajectory of an existing flight between the origin and destination for that same equipment category.

4.5 Assignment of Trajectories - Enhanced Scenario

A trajectory generator called Optimized Trajectory Generator (OPGEN) (see Appendix C for a description of OPGEN) was used to create flight trajectories for the enhanced scenario. Basic assumptions were made. Aircraft performance constraints such as maximum thrust, speed, and others were considered constraint variables in creating flight trajectories. For example, an aircraft cannot fly at a speed greater than its specified performance. The special use airspace (SUA) availability and the activities around SUA were held constant. For example, the direction of flight around the SUA was held constant. Therefore, if a flight goes left around a SUA in 1996, future flights will also go around the SUA in the same direction. Finally, preserving airline schedules is an important factor in future operation of the NAS. If the airlines knew they could leave later (and possibly fill more seats) and still arrive on time, they would rather do that than get to the destination early. Other assumptions are listed below for different, future time frames.

<u>2005:</u>

- Flights flying less than 1,000 nautical miles had their distances reduced (direct routing) when operating at FL240 and above.

- Flights flying greater than 1,000 nautical miles were optimized for minimum fuel when operating at FL240 and above.

2010 and 2015:

- Flights flying less than 1,000 nautical miles had their distances reduced (direct routing) when operating at 15,000 feet and above.

- Flights flying greater than 1,000 nautical miles were optimized for minimum fuel when operating at 15,000 feet and above.

(See Appendix F for additional information on the assignment of trajectories.)

Section

5

ANALYSIS OF THE BASELINE AND ENHANCED SCENARIOS

The following paragraphs describe a) the methodologies and analysis of flights generated in each scenario for in-flight (CONUS), surface, and oceanic; b) the calculation of fuel burned; and c) the subsequent emissions of NOx, HC, and CO. (See Appendices G, H, and I for additional information supporting the analyses described in this section.)

5.1 Airborne (CONUS)

5.1.1 Fuel Burn Calculation and Analysis

Aircraft performance was used to calculate fuel burned for each IFR flight operating in the en route and terminal environments. Aircraft performance data was not available for all aircraft used in this analysis, therefore, two set of algorithms were used to calculate fuel burned. A force balance equation was applied to aircraft for which detailed aircraft performance data was available from LINKMOD[2] data (see Appendix G for fuel burn calculations). For those aircraft without performance data, fuel burn was computed in a manner similar to that used in deriving the Breguet[3] range equation.

5.1.1.1 Aircraft with Performance Data

For many flights, the aircraft model was available only in a general manner (e.g., B727) and did not contain the specific version model (e.g., –100 versus –200). In order to assign a specific (aircraft type and version number) model to each flight, the airline ID (e.g., UAL, AAL, etc.) in the flight identifier was used. Assignment of specific model type was based on the airline's fleet and the relative number of different aircraft models. When no airline model was available, the version number selected was the most popular for that aircraft type.

A second factor in aircraft fuel burn is the weight of the aircraft. In order to compute the fuel consumed by a flight, the weight of the aircraft at landing was estimated by assuming a passenger load factor of 70% and landing with 45 minutes of reserve fuel. The maximum number of passengers on board was an average across the industry.

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[2] LINKMOD is a FAA model for calculating fuel burn based on the energy balance equation.
[3] Kerrebrock, J.L., "Aircraft Engines and Gas Turbines, " 1984

Given the aircraft type (performance data), aircraft weight and trajectory, the total fuel consumed by the flight was calculated using an ordinary differential equation.

5.1.1.2 Aircraft without Performance Data

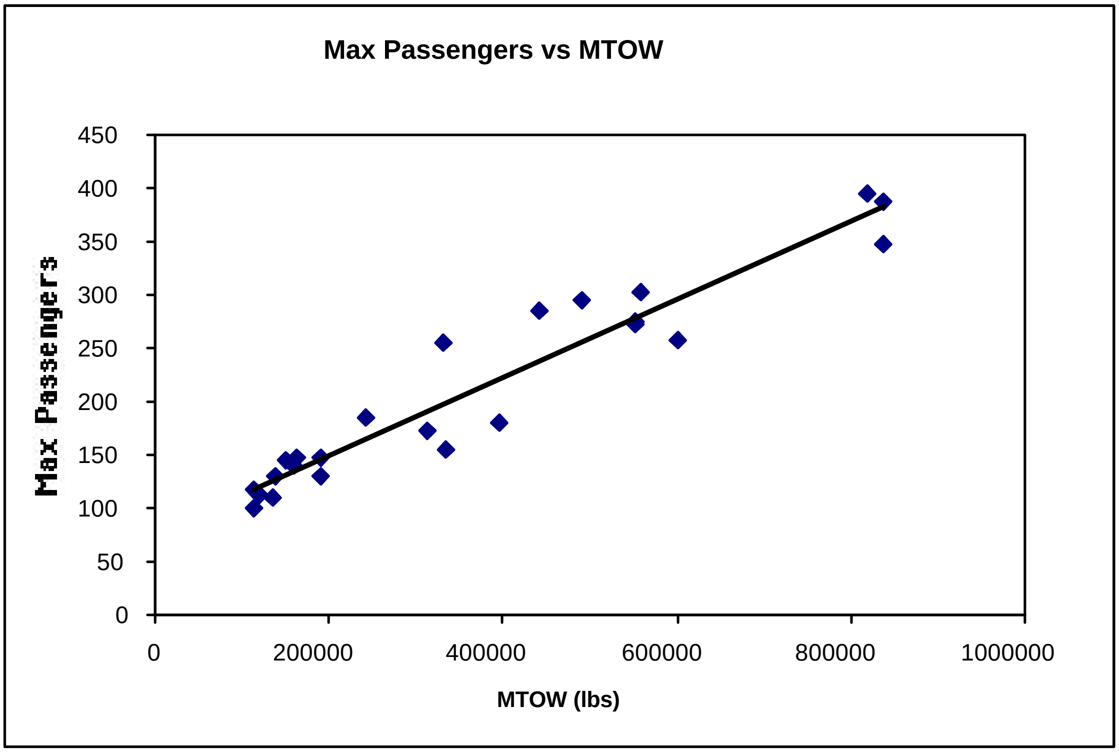
For aircraft without performance data, the weight at landing was estimated from the maximum allowable takeoff weight for the aircraft. It was assumed there would be a constant specific impulse and the aircraft operated at a roughly constant lift-to-drag (L/D), therefore a simplified equation was applied.

Similar to the previous section, the aircraft fuel burned was a function of the aircraft weight, assumed aircraft performance, and its trajectory.

5.1.1.3 New Aircraft

Finally, when a new aircraft type was projected to enter the fleet, the maximum weight of the aircraft was derived from the number of passengers expected in this new aircraft. This was accomplished by extrapolating the best-fit line from the existing data on number of passengers versus maximum takeoff weight (MTOW) of known aircraft as shown in Figure 5-1. Once the maximum takeoff weight was obtained, the new aircraft was treated in a manner similar to aircraft with no model available.

Figure 5-1. Relationship between Maximum Number of Passengers and MTOW



5.1.2 Sample Flight Trajectories

After all data preparation was completed, the baseline scenario contained a set of IFR flight plan trajectories for a day in 1996, 2005, 2010, and 2015 similar to the one shown in Table 5-1. The enhanced scenario contained a similar set of wind-optimized trajectories for all years except 1996. There were 46,102 such flights in 1996 and 56,900 flight trajectories for 2015. These included air carrier, air taxi/commuter, general aviation, and military.

The first line of the data in Table 5-1 below indicates that this is a Boeing 737-200 flying from Philadelphia to Cleveland. There are 25 segments for the flight with the following data in each segment: cumulative elapsed time in minutes, fuel consumption, altitude in hundreds of feet, mach speed, latitude, and longitude.

Table 5-1. Sample Flight Trajectory

46.XYZ01175.B737 PHL CLE
25

Cum. Time (Minutes)	Fuel/Seg. (Pounds)	Alt. (100 Ft.)	Mach Speed	Latitude	Longitude
0.000	169.481	0	0.529	39.870	-75.230
0.820	236.594	29	0.554	39.928	-75.305
2.033	311.750	66	0.590	40.031	-75.398
4.316	346.367	112	0.436	40.209	-75.560
6.848	156.393	152	0.542	40.400	-75.683
8.122	170.230	171	0.531	40.424	-75.821
9.485	327.505	191	0.552	40.450	-75.967
12.355	131.133	227	0.585	40.500	-76.283
13.551	74.542	240	0.607	40.522	-76.418
14.270	91.680	248	0.606	40.539	-76.499
15.127	26.551	257	0.623	40.560	-76.596
16.281	265.111	269	0.652	40.589	-76.731
19.063	314.910	290	0.666	40.659	-77.064
22.980	285.803	300	0.672	40.755	-77.535
26.885	284.919	300	0.671	40.849	-78.006
30.786	260.651	300	0.670	40.938	-78.479
34.686	264.454	290	0.664	41.026	-78.953
38.576	97.495	280	0.661	41.109	-79.429
40.817	75.121	240	0.662	41.157	-79.710
42.361	238.818	212	0.645	41.183	-79.909
46.093	48.240	159	0.619	41.244	-80.393
46.877	209.398	147	0.590	41.257	-80.493
50.159	355.112	99	0.503	41.304	-80.878
54.578	136.181	47	0.486	41.361	-81.364
58.790	0.0	0	0.486	41.400	-81.830

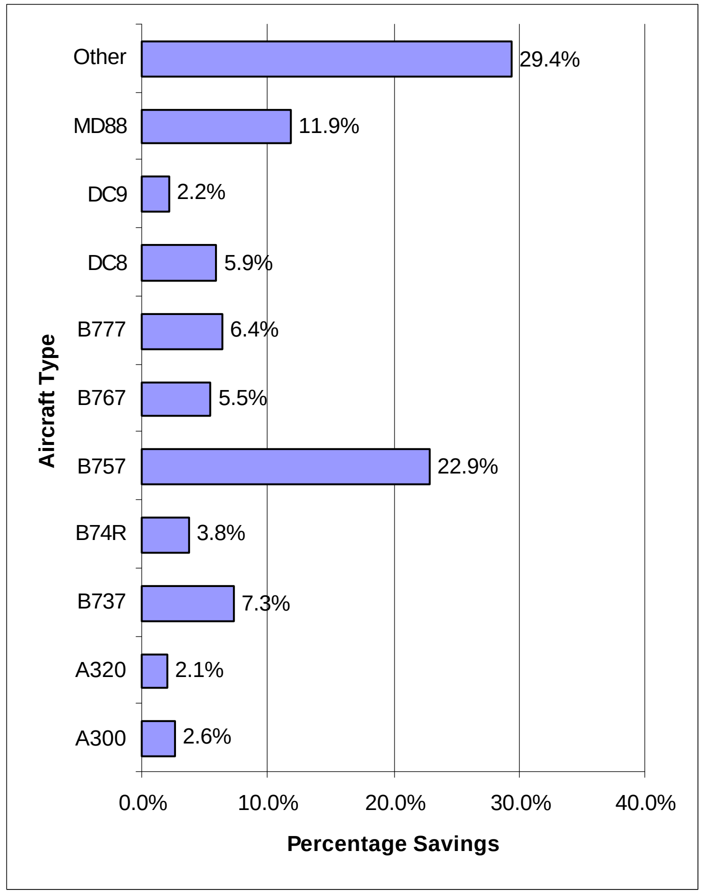
5.1.3 Analysis of Flight Trajectories

The analysis of flight trajectories was divided into two components, above and below 3000 feet. This division was made to accommodate emission calculations, which will be described in paragraph 5.4. The phase of flight above 3,000 feet offers capability for more fuel-efficient flight operations and accounts for most of the savings. A comparison of the flight trajectories and fuel consumption between the baseline and enhanced scenarios in 2015 results in a daily fuel saving of 17.4 million pounds for all flights. This saving is a direct result of more fuel-efficient trajectories and does not include savings due to reduced airborne delay, which is discussed in Section 5.1.5. Over 70% of the daily fuel savings occurred in the 10 aircraft listed in Table 5-2.

Table 5-2. Fuel Savings in 2015 by Type Aircraft (lbs.)

Aircraft Type	Name	Baseline	Enhanced	Fuel Savings	Percentage Savings
B757	Boeing 757	68,708,125	64,718,986	3,989,139	6.2%
MD88	McDonnell-Douglas 81-88	46,795,851	44,730,766	2,065,085	4.6%
B737	Boeing 737-300/400 Series	48,791,750	47,516,432	1,275,317	2.7%
B777	Boeing 777	15,741,489	14,625,496	1,115,992	7.6%
DC8	McDonnell-Douglas 8	10,915,558	9,890,987	1,024,571	10.4%
B767	Boeing 767	20,180,560	19,219,538	961,022	5.0%
B74R	Boeing 747-SR	11,728,527	11,072,394	656,134	5.9%
A300	Airbus 300	9,581,057	9,121,290	459,767	5.0%
DC9	McDonnell-Douglas 9	11,961,611	11,574,832	386,778	3.3%
A320	Airbus 320	8,991,694	8,629,766	361,928	4.2%
		253,396,221	241,100,487	12,295,734	5.1%

Figure 5-2. Percent of Total NAS Fuel Savings Above 3,000 Feet 2015



These fuel savings during the en route and cruise phases of flight result from CNS/ATM enhancements that provide improved decision support tools, improved information, and better position accuracy. The enhancements allow users to fly preferred routes that include optimum climb/descent and wind-optimized trajectories. Many of today's ATC restrictions will be removed, making structured routes the exception rather than the rule.

In the enhanced scenario, aircraft flying trajectories above 15,000 feet and distances in excess of 1,000 miles will receive the most benefit from CNS/ATM enhancements that provide capability for users to fly wind-optimized and cruise climb and descent trajectories. Of all the aircraft types included in the enhanced scenario, the Boeing 757 accounted for 22.9% of the total fuel savings for all flights modeled, as shown in Figure 5-2.

5.1.4 Arrival Airports

Efficiency savings from CNS/ATM enhancements realized during en route and cruise phases extend to the terminal area for arrivals and departures. A savings will result from increased information exchange, automated decision support tools for merging and sequencing traffic, and increased use of area navigation.

Flight trajectories above 3,000 feet were analyzed by arrival airports and indicated that the top 10 airports shown in Table 5-3 and Figure 5-3 account for 32% of daily flight trajectory fuel savings in 2015.

Table 5-3. Fuel Savings in 2015 by Arrival Airport (lbs.)

Airport ID	Airport Name	Baseline	Enhanced	Fuel Savings	Percentage Savings
ORD	Chicago O'Hare Int'l	14,029,784	13,090,414	939,370	7.2%
DFW	Dallas/Ft. Worth Int'l	16,042,454	15,004,745	1,037,709	6.9%
LAX	Los Angeles Int'l	18,889,618	17,814,106	1,075,512	6.0%
ATL	Atlanta Int'l	8,902,309	8,524,580	377,728	4.4%
DTW	Detroit Metro Wayne Co.	6,859,840	6,416,142	443,698	6.9%
MIA	Miami Int'l	5,413,989	5,169,116	244,873	4.7%
PHX	Phoenix Sky Harbor Int'l	7,804,984	7,337,076	467,909	6.4%
STL	St. Louis Int'l	6,140,680	5,867,773	272,907	4.7%
OAK	Oakland Int'l	2,459,199	2,313,867	145,332	6.3%
MSP	Minneapolis/St. Paul Int’l	7,997,762	7,432,699	565,063	7.6%
		94,540,620	88,970,518	5,570,102	6.3%

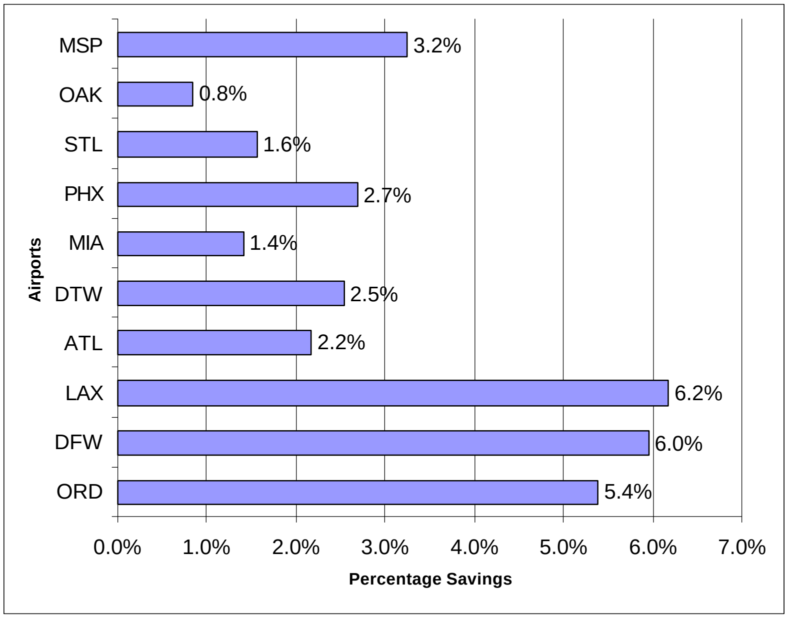


Figure 5-3. Percent of Total NAS Fuel Savings - 2015

5.1.5 Airborne Delay

Fuel burn was calculated for airborne delay by airport and aircraft type below FL240 for 1996 and 2005, and below 15,000 feet for 2010 and 2015. Airborne operational delay increases the fuel burn and accumulates when the demand exceeds the airport's capacity. There are four contributing factors in the model that account for airborne operational delay: 1) flow control restrictions, 2) arrival/departure fix limits, 3) sector capacities, and 4) arriving flights holding for occupied runways.

Flow control restrictions are defined as static or dynamic. Static flow control restrictions usually are positioned at center boundaries and are used to adjust traffic flow rates where congested Terminal Radar Approach Controls (TRACONS) are known to exist. Dynamic flow control restrictions appear during the course of the simulation when large amounts of traffic are heading toward major airports. The flow control restrictions provide additional spacing requirements on flights passing through the restriction.

Arrival and departure fixes also have minimum spacing requirements between successive flights associated with them and are located near the airport. They are spaced strategically to feed the traffic flow for the en route airspace.

Sector entry delay occurs when the instantaneous or hourly aircraft count parameters for a sector are exceeded. Sector capacities were provided by Air Traffic for all sectors modeled. The model records delay at sector boundaries when the Monitor Alert Parameter (MAP) is exceeded for any instance of time.

In addition, flights waiting to use an occupied runway incur airborne operational delay. This type of delay is caused by demand exceeding the arrival capacity of an airport. The service interval between successive arrivals is a function of the capacities currently in use at the airport and the respective arrival and departure queue lengths.

Comparison of airborne delays for the baseline and enhanced scenarios in 2015 resulted in daily fuel savings of 5.7 million lbs. for all flights in the NAS. This represents 25% of the total airborne fuel savings of 23.2 million lbs., with the other 75% due to more efficient flight trajectories as described in Section 5.1.3.

5.2 Surface Operations

Surface operations enhancements will result in improved aeronautical, departure clearance, and surface management information exchange between the service provider and users. The addition of surface automated aids will improve taxi sequencing and spacing of aircraft to departure thresholds, thus balancing taxiway usage.

The analysis evaluated taxi times and ground delays at each airport. Ground delay accumulates at airports when flights enter and hold in departure queues during the taxi-out process. Departure queues increase when the demand for departures exceeds the airport's maximum departure capacity. These capacities are dependent on the airport's runway configurations and projections of future airport improvements.

5.2.1 Fuel Burn

Surface fuel burn was calculated for each of the airports. The total ground delay time (the amount beyond the unimpeded time for all aircraft due to waiting in the departure queue) was applied to each aircraft type that was departing from an airport within the CONUS. The idle ICAO fuel flow rate was used in the following calculation:

*Fuel Burn Per Flight = Fuel Rate Lbs. Per Minute * (Total Ground Delay Time + (Unimpeded Taxi Time * Number of Aircraft)) * Number of Engines*

For all flights arriving within the CONUS, the same formula was used except that the delay time was set to zero.

5.2.2 Surface Taxi Time

The unimpeded taxi times were a key input parameter to the NASPAC simulation for measuring ground delay and calculating the amount of time on the surface for both the baseline and enhanced scenarios. Unimpeded taxi times, developed and provided by Office of Aviation Policy and Plans (APO-130), Information Systems Branch, were applied to both the taxi-out and taxi-in conditions for each of the 80 modeled airports (see Appendix J for a list of airports and their taxi-in and taxi-out times). An average taxi-out and unimpeded taxi-in time was applied to the remaining airports.

The unimpeded taxi-out condition occurs when the departure queue is equal to 1 and the arrival queue is equal to 0. Similarly, the unimpeded taxi-in condition occurs when the aircraft's wheels hit the runway and the aircraft taxis immediately to its respective gate. An unimpeded time is developed from the Airline Service Quality Performance (ASQP) data, which is reported airline data to the Department of Transportation (DOT) from the 10 largest carriers. It is computed for each airport based on airport, carrier, and season. Because gate positions of the different carriers may vary considerably depending on the airport, the average for each airport by carrier and season was used for this analysis.

Typically, an airport's unimpeded taxi-out time varies widely from its median taxi-out time, especially at the busier airports, e.g., EWR's unimpeded taxi-out time (11.7 minutes), and DFW's (9.9 minutes) are in about the 15th percentile for all of their flights. In contrast, non-busy airports, such as Dallas Love (DAL) and Indianapolis (IND) typically have unimpeded taxi times that are very close to the median. Unimpeded taxi-in times have less variability than taxi-out times and are on average about half of the taxi-out time.

In the enhanced scenario, the unimpeded taxi-out and taxi-in times were reduced by 5% for ATL in 2005 and the 12 airports that were expected to benefit from the Surface Movement Advisor (SMA). The 12 airports are Boston Logan International Airport (BOS), Dallas Fort Worth

Airport (DFW), Detroit Metropolitan Airport (DTW), Newark Airport (EWR), Los Angeles International Airport (LAX), Orlando International Airport (MCO), Miami International Airport (MIA), Minneapolis–St. Paul International Airport (MSP), O'Hare International Airport (ORD), Pittsburgh International Airport (PIT), San Francisco International Airport (SFO), and St. Louis International Airport (STL). In 2015, all other modeled airports had reduced taxi times of 5% from the 1996 baseline number.

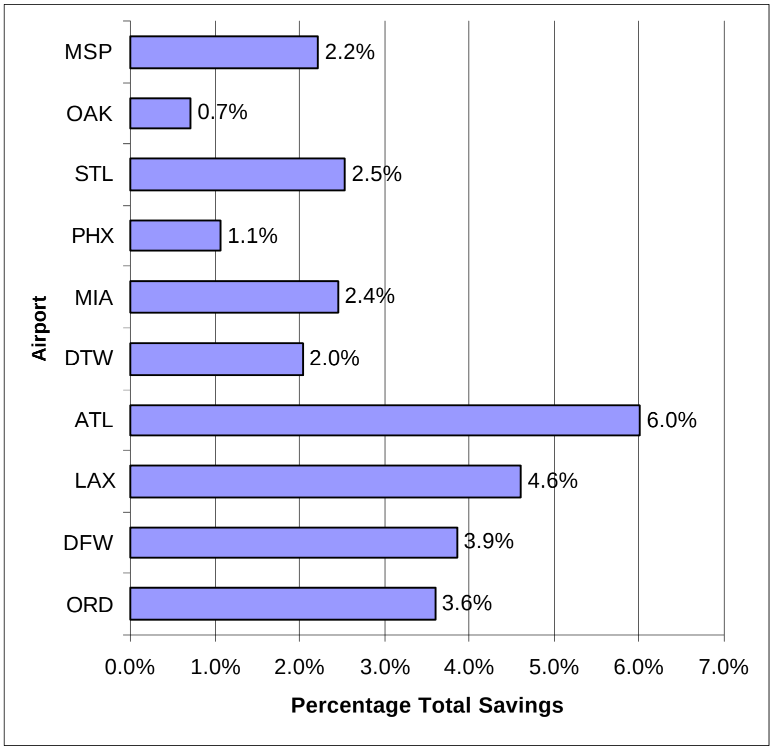
While it is difficult to extrapolate for the NAS based on observations from ATL, the NAS architecture does not address time frame reductions explicitly. The study team assumed that inferences could be made from the portrayed future improvements of the surface management system (SMS), such as cockpit moving maps and ADS-B implementation.

Ground delays, as discussed in the previous section, were computed from the NASPAC simulation by airport and aircraft type. The time spent by an aircraft in the departure queue was added to the airport's respective unimpeded taxi times. This resulted in daily fuel savings of over one million lbs. for all airports modeled. The top 10 airports for surface fuel savings are shown in Table 5-4 and Figure 5-4, and account for 29% of the total surface fuel savings.

Table 5-4. Fuel Savings in 2015 by Airport (lbs.)

Airport ID	Airport Name	Baseline	Enhanced	Fuel Savings	Percentage Saving
ORD	Chicago O'Hare Int'l	789,255	752,411	36,845	4.9%
DFW	Dallas/Ft. Worth Int'l	809,480	770,086	39,394	5.1%
LAX	Los Angeles Int'l	839,422	792,443	46,979	5.9%
ATL	Atlanta Int'l	715,231	653,910	61,321	9.4%
DTW	Detroit Metro Wayne Co.	460,250	439,423	20,826	4.7%
MIA	Miami Int'l	520,664	495,703	24,961	5.0%
PHX	Phoenix Sky Harbor Int'l	432,692	421,828	10,864	2.6%
STL	St. Louis Int'l	566,798	540,988	25,811	4.8%
OAK	Oakland Int'l	153,919	146,601	7,319	5.0%
MSP	Minneapolis/St. Paul Int’l	590,679	567,967	22,712	4.0%
		5,878,391	5,581,359	297,032	5.3%

Figure 5-4. Percent of Total NAS Surface Fuel Savings – 2015



5.3 Oceanic

The oceanic air traffic environment is different from the domestic environment in a number of aspects, rendering oceanic air traffic control much less efficient than domestic. With most oceanic routes out of range of radar and direct communications and with manual tracking of flight progress, aircraft separation standards over the ocean are very large, and there is minimal flexibility to modify flight plans.

Proposed advanced automation, direct and reliable communications, improved navigation and surveillance, and more timely and accurate weather data will greatly improve the efficiency of oceanic air traffic control and will allow for significant reduction of required separations.

5.3.1 Oceanic Fuel Savings

Calculable fuel savings were found to be available in two categories: delay and efficiency. Delay benefits are the savings obtained by reducing the amount of time spent waiting for an acceptable oceanic routing. Efficiency benefits are the fuel savings obtained by flying closer to the aircraft's optimal routes, altitudes, and speeds.

The primary source of predicted fuel savings is a simulation model developed for the Oakland oceanic airspace and run by the MITRE Corporation Center for Advanced Aviation System Development (CAASD). The model provided an analysis capability to compute fuel burn and flight time for both actual and preferred flight trajectories. The simulation model was run using a variety of input assumptions as to density and separation standards to determine the effects of each.

Current oceanic forecasts predict lower rates of growth than those used in 1996, when the original MITRE simulation model was run; therefore, the predicted annual fuel savings were adjusted for the lower growth rates and lower projected user equipage rates.

The type aircraft used for oceanic flights in the North Atlantic and Pacific airspace and their relative fuel consumption were available for the years 1996 and 2002 as shown in Table 5-5. These were coupled with hourly fuel consumption figures by type aircraft to calculate estimated savings by year in U.S. North Atlantic and Pacific airspace as shown in Table 5-6.

Table 5-5. Relative Oceanic Fuel Consumption by Aircraft Type

	Percent of 1996 Fleet			Percent of 2002 Fleet			1996	2002
Aircraft Type	Pacific	Atlantic	Total	Pacific	Atlantic	Total	Percent of Fuel	Percent of Fuel
A300	0.0%	2.1%	0.8%	0.0%	0.0%	0.0%	0.5%	0.0%
A310	0.0%	6.0%	2.4%	0.0%	4.0%	1.6%	1.4%	1.0%
A330	0.3%	1.0%	0.6%	1.7%	10.0%	5.0%	0.4%	3.7%
A340	5.1%	3.0%	4.3%	11.1%	11.0%	11.1%	3.0%	8.3%
B727	0.4%	2.0%	1.0%	0.0%	0.0%	0.0%	0.4%	0.0%
B747-200	31.7%	18.5%	26.6%	21.7%	8.2%	16.4%	35.8%	23.9%
B747-400	24.7%	14.5%	20.7%	25.7%	9.8%	19.4%	25.7%	26.0%
B757	0.3%	11.0%	4.5%	0.0%	7.0%	2.7%	1.6%	1.0%
B767	0.6%	16.0%	6.6%	2.2%	15.0%	7.2%	3.5%	4.1%
B777	0.6%	2.9%	1.5%	14.5%	19.0%	16.3%	1.0%	12.4%
DC-10	15.3%	9.0%	12.8%	10.1%	6.7%	8.8%	11.4%	8.4%
L-1011	5.9%	2.9%	4.7%	0.0%	0.0%	0.0%	3.8%	0.0%
MD-11	11.7%	5.8%	9.4%	10.5%	6.9%	9.1%	8.1%	8.5%
MD-80/ DC8	0.4%	2.0%	1.1%	0.0%	0.0%	0.0%	0.3%	0.0%
C-5	1.1%	1.1%	1.1%	1.0%	1.0%	1.0%	1.5%	1.5%
C-141	1.7%	1.7%	1.7%	1.5%	1.5%	1.5%	1.2%	1.2%
C-135	0.4%	0.4%	0.4%	0.0%	0.0%	0.0%	0.3%	0.0%

Table 5-6. Oceanic Fuel Savings by Air Traffic Control Center - 2015

	Estimated Fuel Consumed (Millions Of Gallons)					
	Oakland	**New York**	**Anchorage**	**Total**	**Saved**	**Pct Saved**
1996	3,429	1,468	587	5,484	0	0.0%
1997	3,627	1,627	683	5,937	0	0.0%
1998	3,707	1,670	715	6,093	4	0.1%
1999	3,870	1,735	747	6,352	15	0.2%
2000	3,945	1,791	761	6,497	34	0.5%
2001	4,115	1,873	794	6,782	54	0.8%
2002	4,087	1,853	828	6,768	69	1.0%
2003	4,264	1,930	864	7,058	83	1.2%
2004	4,448	2,008	902	7,358	106	1.4%
2005	4,641	2,086	941	7,668	126	1.6%
2006	4,859	2,166	985	8,010	135	1.7%
2007	5,088	2,237	1,031	8,356	144	1.7%
2008	5,328	2,332	1,080	8,740	154	1.8%
2009	5,579	2,418	1,131	9,128	165	1.8%
2010	5,841	2,508	1,184	9,533	178	1.9%
2011	6,116	2,600	1,240	9,957	194	1.9%
2012	6,404	2,697	1,298	10,399	211	2.0%
2013	6,706	2,796	1,359	10,862	228	2.1%
2014	7,022	2,900	1,423	11,345	246	2.2%
2015	7,352	3,007	1,490	11,850	265	2.2%

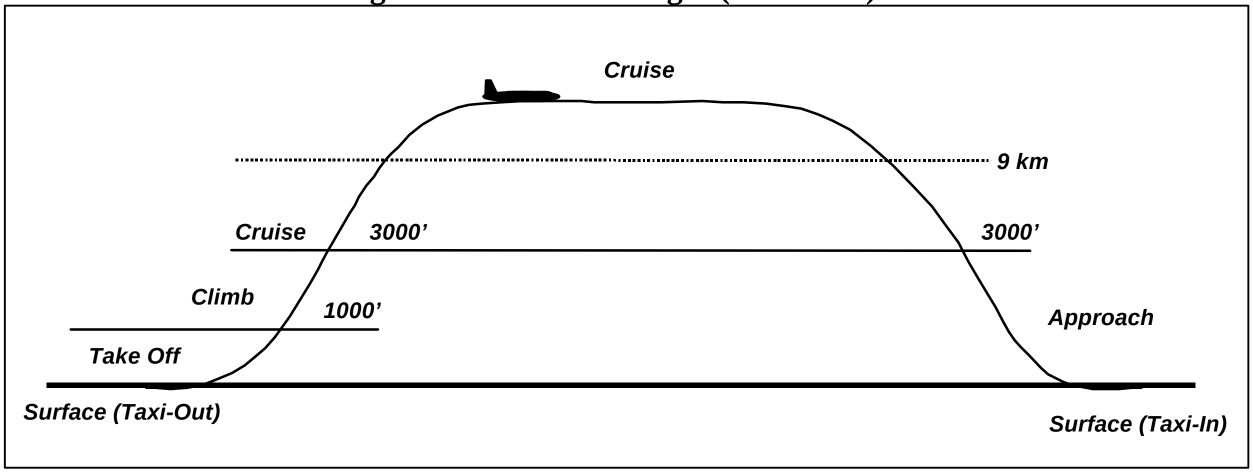
In addition to the above, better CNS and automation capabilities will provide more flexibility for controllers to grant pilot requests (e.g., for altitude changes) and will enable much faster responses by controllers. These benefits were not captured in the simulation model.

A number of factors could affect the level of benefits accrued. For example, higher levels of traffic or more rapid SATCOM/Data Link equipage would increase benefits. By contrast, lower levels of oceanic traffic, the introduction of more efficient aircraft, or delays in the reduction of aircraft separation minima would reduce benefits attributable to ATC improvements.

5.4 Emissions

The climb-out and cruise phases of flight used for emission calculations (illustrated in Figure 5-5) are different from those used for conventional phases of flight. This is due to the fact that emission dissipation acts differently closer to the ground than higher in the atmosphere. Therefore, the climb out phase is considered to be from 1,000 feet to 3,000 feet instead of continuing until the aircraft levels off. In addition to the change in climb out altitude, the cruise indices are separated into two altitude levels (0-9 km and 9-13 km) to reflect more accurately the difference in emissions (due to changes in pressure and temperature) between lower and higher cruise levels.

Figure 5-5. Phase of Flight (Emissions)



FAA-AEE and ICAO provided the algorithm for converting fuel burned to emissions of gases. The data sources and equations provide a means to calculate the emissions of gases from surface to 3,000 feet. The Landing and Take-Off (LTO) Cycle is in accordance with Environmental Protection Agency (EPA) guidance. NASA and the Boeing Aircraft Company provided data and equations for calculating emissions of gases above 3,000 feet. In order to convert fuel burn into emissions, the following emissions formula[4] was used.

*Emissions (lbs.) = Time (min.) * Fuel Flow (1000 lbs./min.) * Emission Index (lbs. emission/1000 lbs. fuel)*

One of the main factors in the equation above is the emission index. The emission index is a function of the engine type, phase of flight (or engine thrust), and pollutant. The emission indices are based on information provided by the engine manufacturers and documented by the FAA and ICAO. These indices (which are referred to as "ICAO indices") were used in the calculations for emissions released during takeoff, climb out, approach, and taxi/idle. (See Appendix K for ICAO Indices.)

However, because the ICAO indices are available only for takeoff, climb out, approach, and taxi/idle, they do not represent emissions above 3,000 feet. Therefore, under contract with NASA, Boeing developed indices for the cruise phase of flight incorporating the ICAO indices and several other factors. These indices (referred to as the "Boeing Method #2 indices") were used to calculate emissions in the cruise phase of flight. If a Boeing Method #2 index was not available for a specific engine type, the ICAO approach index was used in its place.[5] (See Appendix K for Boeing Method #2 Indices.)

[4] Source: Procedures for Emission Inventory Preparation, Volume IV, Mobile Sources, EPA, Ann Arbor, MI, 1992.
[5] ICAO approach indices were used for cruise indices when Boeing indices were not available, as recommended by Steve Baughcum and Steven Henderson from Boeing.

Because the emission indices are engine specific, it was necessary to map the aircraft types to specific engine types. (See Appendix H for Cross Reference to Engines.) The first step in the mapping process was to map all of the aircraft types from the scenarios to known aircraft types using the characteristics of the aircraft (i.e., size, jet vs. turboprop, number of engines, etc.). In many cases, the aircraft types were the same. In the case of an unknown aircraft type, it would be mapped to a Cessna Citation. Once the aircraft types were assigned, the default engine for each aircraft type was extracted from both the ICAO document and the Boeing Method #2 document. When there was no default engine specified in either document, the default engine from Emissions and Dispersion Modeling System (EDMS) was used. Once the default engine was determined, the appropriate emission index could be used for each aircraft type.

Section 6

SUMMARY

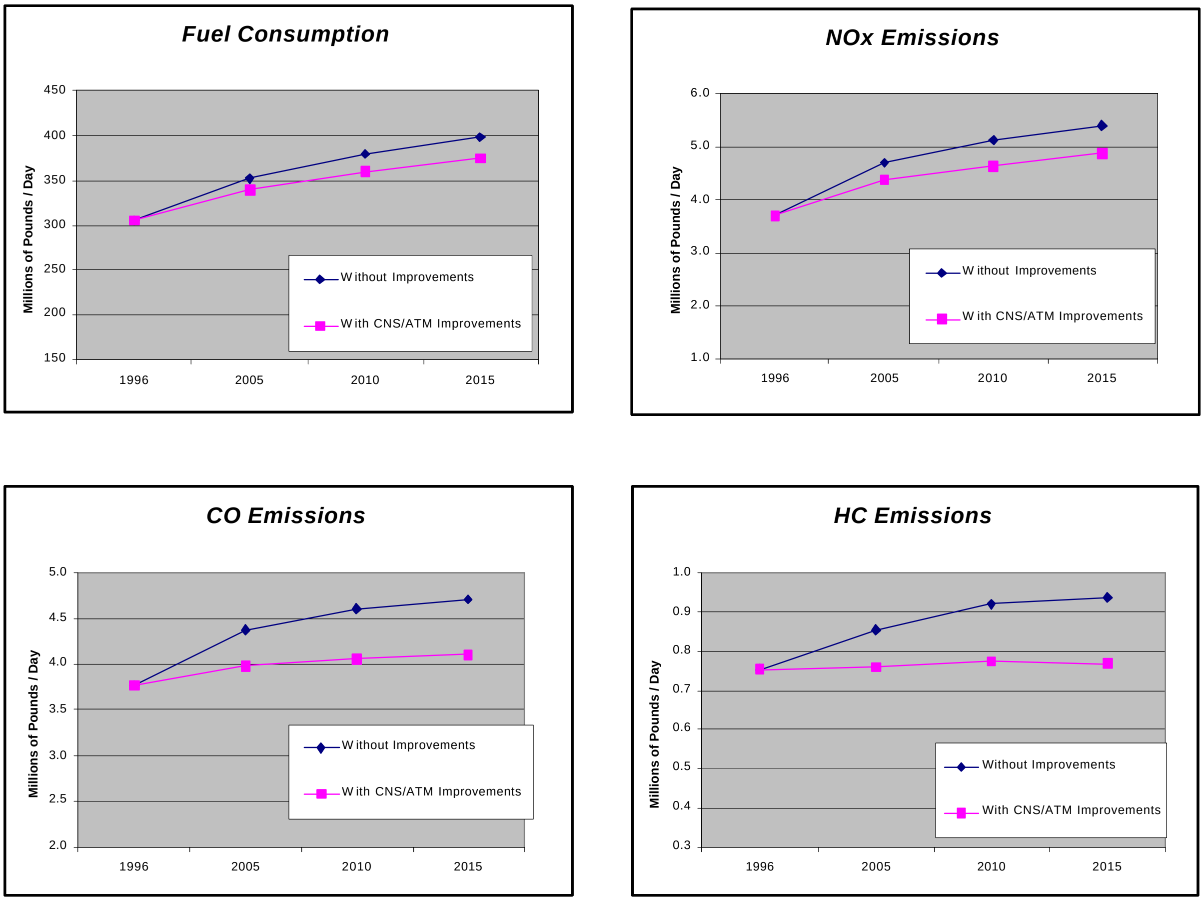
A summary of the daily fuel and emission calculations for each year of the baseline and enhanced scenarios is shown in Table 6-1, and depicted graphically in Figure 6-1.

A comparison of the baseline and enhanced scenarios in 2015 provided the daily fuel and emission savings resulting from NAS Modernization. Fuel savings exceeded 24.3 million lbs., of which 17.4 million were due to more efficient trajectories, over 5.7 million were due to reduced airborne delay, and the remaining one million lbs. derived from reduced surface delay. The emission savings resulting from reduced fuel burn in the various phases of flight were 9.9% for NOx, 12.7% for CO, and 18.0% for HC, as shown in Table 6-1 and depicted graphically in Figure 6-1.

Table 6-1. Fuel and Emission Savings (000 lbs.)

		Baseline Case				CNS/ATM Improvements							
Year	**Mode**	**Fuel**	**NOx**	**CO**	**HC**	**Fuel**		**NOx**		**CO**		**HC**	
1996	**Total**	**305,805**	**3,712**	**3,772**	**754**								
	Above 3000	253,195	3,100	2,926	569								
	Below 3000	33,380	547	200	19								
	Surface	19,231	65	647	166								
2005	**Total**	**351,964**	**4,708**	**4,373**	**854**	**339,240**	**-3.6%**	**4,377**	**-7.0%**	**3,974**	**-9.1%**	**758**	**-11.2%**
	Above 3000	292,604	3,935	3,431	657	280,656		3,609		3,041		563	
	Below 3000	38,346	702	195	19	37,824		698		191		18	
	Surface	21,013	72	747	177	20,759		71		742		176	
2010	**Total**	**380,176**	**5,126**	**4,607**	**919**	**359,263**	**-5.5%**	**4,636**	**-9.5%**	**4,059**	**-11.9%**	**773**	**-15.9%**
	Above 3000	317,224	4,292	3,595	713	297,424		3,810		3,074		572	
	Below 3000	40,414	757	194	19	40,041		752		192		18	
	Surface	22,538	77	817	188	21,797		75		793		183	
2015	**Total**	**399,157**	**5,399**	**4,706**	**937**	**374,953**	**-6.1%**	**4,867**	**-9.9%**	**4,109**	**-12.7%**	**768**	**-18.0%**
	Above 3000	333,192	4,513	3,666	727	310,633		3,996		3,110		568	
	Below 3000	42,756	806	198	19	42,132		795		195		19	
	Surface	23,209	80	842	191	22,188		76		804		182	

Figure 6-1. Fuel and Emission Savings



6.1 Annualization

The study was based on a representative day in the NAS, Tuesday, November 12, 1996. Results were then extended to annual savings. Multiplying the results by 365 would give annualized results only if traffic demand on all days in the year were comparable. However, traffic demand varies by day of the week and season. An analysis of the weekday and seasonal demand variations for 1996 resulted in a conversion factor of .96. This was primarily because the weekend traffic demand is less than that for a weekday. Daily results from the analysis were extended to annual savings in fuel and emissions by multiplying by 365 * .96. See Table 6-2 below.

Table 6-2. Annual Savings in Millions of Pounds

Phase of Flight	Fuel	NOx	CO	HC
Above 3,000	9,683	204.3	197.1	56.7
Below 3,000	219	4.0	1.1	0.1
Surface	358	1.2	13.2	3.1
Total	10,259	209.5	211.4	59.9
% Savings	6.1%	9.9%	12.7%	18.0%

6.2 Conversion of Fuel to Dollars

Economic savings were not the principle objective of this study; however, they are frequently of interest in evaluating investments such as CNS/ATM enhancements. In order to convert the fuel savings to dollars, the fuel was first converted from pounds into gallons by dividing by a factor of 6.7 for air carriers and military, and a factor of 6.0 for GA. Gallons of fuel saved were then multiplied by cost per gallon to determine the annual cost savings to users of the airspace system. ATA provided the FAA with cost of fuel and fuel consumption figures for all the major air carriers, national and large regional, over the last year. From this information, it was determined that the cost per gallon of fuel for air carriers, including air taxis/commuter, ranged from $0.51 - $0.68. An average of $0.60 was used in the analysis. Using fuel price information from AirNav and a sampling of GA pilots, it was determined that the cost per gallon of fuel for GA ranged from $1.37 - $3.95, with a national average of $2.08 used in the analysis. From this, the annual savings in 2015 were shown to be $1.0 B (in 1998 dollars). See Table 6-3 below.

Table 6-3. 2015 Annual Savings (in millions of 1998 $)

	Air Carriers/Mil	**GA**	**Total**
Lbs. of Fuel Savings	9,913	346	10,259
Gallons of Fuel Savings	1,480	58	1,537
Dollars of Savings	**$888**	**$120**	**$1,008**

Section 7

CONCLUSION

Fuel conservation and environmental protection have been long standing U.S. national priorities. The findings from this study indicate that Free Flight capabilities provided by planned CNS/ATM enhancements in the NAS Architecture clearly contribute to the realization of these national goals.

The key finding from this study indicates that aircraft flying in U.S. airspace could potentially reduce annual fuel burn by about 10 billion lbs. in the year 2015. This estimated fuel savings in effect represents a 6% reduction in the amount of fuel that would have been burned without NAS modernization. The fuel saving results in corresponding reductions of over 209 million lbs. of NOx, 211 million lbs. of CO, and 59 million lbs. of HC, representing reduced emission levels of 9%, 12% and 18%, respectively.

The fuel savings, resulting from more fuel-efficient trajectories, wind routes, and more efficient traffic handling capabilities, is estimated to provide an economic fuel benefit of about $1.0B (in 1998 dollars) in 2015 to the airspace users. On top of this economic fuel benefit potential, airlines also will experience other operating cost savings associated with reduced delays and more efficient flight paths resulting from the CNS/ATM improvements.

In general, this study has shown that there are positive environmental and economic benefits to be realized with the planned improvements in CNS/ATM capabilities by the FAA in support of Free Flight initiatives. The estimated savings in fuel to users and reduced emissions to society are considerable. Modernizing the NAS thus benefits not only the airspace users, but also the environment.

APPENDICES

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